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Designing and Implementing an "Intelligent" Multimedia Tutoring System for Repair Tasks: Final Report

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This document contains three items: the final report for the ONR contract Designing and Implementing an Intelligent Multimedia Tutoring System for Repair Tasks; a technical report titled Sequencing and Access in Interactive Graphics-based Procedural Instructions, and an Appendix listing papers, talks, and technical reports completed during the project. The final report gives an overview of the three major phases of the work: (1) Developing an interactive computer-controlled videodisc-based system to help people learn to assemble an object, and testing how people use it; (2) Designing and implementing a prototype "intelligent" multimedia tutoring system (videodisc-based) to help people assemble, repair, and understand an object, and testing how people, given different tasks, use it, and (3) Developing an interactive graphics-based system to help people repair an object, and testing how people use several versions of it. The technical report gives

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18. multimedia presentations, procedural instruction, practice, organization in interactive instruction, "hypergraphics".

19. details of (3) reporting a surprising result that for the interactive materials studied, organization did not play a role in performance. This is in strong contrast to the important role of organization in passive instruction.

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Final Report of Office of Naval Research Contract, Designing and Implementing an Intelligent Multimedia Tutoring System for Repair Tasks (N00014-85-K-0060)

The purpose of this report is to describe a research project which began in September 1984 at the University of Colorado and ended in April 1989 at the University of Michigan. There were three main phases in the work, two at Colorado and one at Michigan. The phases were:

1. Developing an interactive computer-controlled videodisc-based system to help people learn to assemble an object, and testing how people use it.
2. Designing and implementing a prototype "intelligent" multimedia tutoring system, again videodisc-based, to help people assemble, repair,and understand an object, and testing how people, given different tasks, use it.
3. Developing a graphics-based system to help people repair an object, and testing how people use several versions of it.

For each phase, a summary of the work will be given generally as follows: the problem or goal will be described, and then the approach (theoretical and practical), the equipment and implementation, experimental work, and results/conclusions/new questions/evaluation of approach. Publications and talks on the research will be listed in an appendix at the end. Attached to this report is a new technical report (Baggett, Ehrenfeucht, & Guzdial, 1989) describing in detail the main study from phase 3, the Michigan phase, so that phase will be described only very briefly in this report.

Phase 1. Videodisc-based procedural instructions.

<u>Problem/goal and approach.</u>

When the project first began, we had been working with film and video instruction. Videodisc was a new medium for us, and there was not much equipment available for combining computerized information and videodisc images in one presentation. The first phase of the work had a modest goal: to develop interactive videodisc-based instructions, under computer control, that help people assemble an object. The instructions were not meant to be "intelligent" in the sense of Sleeman & Brown (1982). There was to be, for example, only one level of instruction for all subjects, and no error diagnosis. But from our earlier ONR-sponsored work in film and video, we had learned how to derive a "natural"

conceptualization (breakdown of the object into parts and subparts), and to find names for parts that were short, easily matched with their physical referents, and fairly well recalled. We used these old techniques in developing the new instructions. In particular, we had developed a videotape showing assembly of an 80-piece object, called a lift, made from the Fischer-Technik assembly kit. It contained the "natural" conceptualization and names, so we pressed a videodisc from that videotape. We then needed to develop instructions under computer control.

Equipment/implementation.

At the beginning of the project we looked for appropriate equipment on which to do our implementation. Lowry Air Force Base in Denver provided us with a Triads system, one of only three or four ever made. It was a two-screen system (videodisc images on one monitor and computer information on another). The system was unique and very nonstandard, and the documentation poor. It eventually broke down, and since there was very little likelihood of making it operable again, we enlisted the help of IBM-Boulder. Phil Smith, the inventor of the IBM InfoWindow system, provided us with a prototype of his system (XT-based, with a special monitor and Pioneer LDV-6000 videodisc player), complete with a beta version of the Composer/Conductor software needed to design presentations. (InfoWindow did not go on the market until about 1986, and this was 1984.)

With Phil Smith and the IBM Advanced Educational Systems group in Atlanta as consultants, we were able to develop our first presentation and help IBM debug its software. Input to the system could be via keyboard and touchscreen; output was moving and still video with text and/or color graphics overlay. There were three sources of speech: two from the two videodisc soundtracks and one from a limited speech synthesizer.

The optical videodisc required by InfoWindow contains up to 54,000 frames, each with its own address. The disc contains up to 30 min of playing time, displaying 30 frames/sec. On our equipment the access time from one frame to any other is approximately 1.6 sec maximum. Our videodisc, pressed from the videotape mentioned above, was 27 min long.

Design of the instructions for assembly of the lift is shown in Figure 1. It was implemented by Jeffery Weiss on an IBM XT-PC, using videodisc and IBM's Composer/Conductor software (since renamed

InfoWindow Presentation System software).

Experimental work/new questions.

Our first goal in the experimental work was to show something that we thought was obvious: that people given interactive control over instructions and the ability to practice (i.e., actually perform the assembly) while they viewed would be able to perform an assembly task later from memory **better** than people who simply viewed videotape instructions without interactive control and without practicing. (Note: By practice we will mean *actually performing the assembly during instruction.*) What we actually found, after running 64 subjects, was not what we expected. We found that there was *no difference* in the two *groups in performing the assembly from memory,* in terms of structural correctness, functionality, or efficiency (correctness divided by total time to work). (Details are in Baggett, 1988.) A side remark is that there were also no gender differences, as we will discuss below.

To try to pin down why interactive instruction with building on-line does not lead to better memory performance than passive video, we first hypothesized that the interactive group had a dual motoric task: build the lift *and* operate the touch screen. We thought that perhaps operating the screen interferes with learning to build. So we reasoned that people who are given interactive instructions and not allowed (during training) to practice would perform even worse from memory than either of the already tested groups. We tested such a group, and to our surprise, it performed no worse on the structural and functional measures, and significantly *better* on the efficiency measure than the first two groups. Clearly we were guessing wrong about the role of practice (motoric actions) in concept formation. We had begun the research with a theoretical model which assumed that motoric, visual, and verbal elements are integrated together into a single concept. But our results indicated that the motoric component seems to stand alone. We have hypothesized a modified framework which says that learning consists of two elements: understanding (a cognitive process) and skill acquisiton (a noncognitive process). Understanding involves forming and modifying concepts. Skill acquisition comes through practice. Understanding is analogous to forming an algorithm, and practice is analogous to executing the algorithm. Most typically when one *executes* an algorithm one does not increase one's understanding (unless during the execution one is noticing something new or debugging the algorithm, i.e., checking that it is okay). Rather, the primary role of practice is to speed up the algorithm's execution. In our experiment, the group which practiced on-line during instruction apparently did not form a less buggy algorithm

than the group which did not practice. But they did perform the memory trial faster (50 min) than the non-practice group (43 min).

Continuing to try to pin down the role of practice, we tested a fourth group whose situation was similar to that of the group that practiced during instruction, but with one difference. During instruction, when they wanted to perform any part of the assembly, they had to indicate this by touching the word "build" on the screen. The screen would then turn black, with the word "return" in the corner. If the subject touched "return," the black screen was replaced by a still frame of the image that had been present just before "build" was touched.

The purpose of the "black screen" experiment was to check whether the decrement in the interactive-build group was one of divided visual attention, namely, having to watch one's hands and the screen simultaneously. With the black screen presentation, one's attention is not divided: one watches either one's hands or the screen. Further, the viewer actually performs a memory trial, broken as he or she wishes into small pieces, during the instructions. That is, he or she is allowed to work only from memory, with just the black screen present; there is no out-and-out copying or mimicking (see also Palmiter, Elkerton, & Baggett, in press).

Results on the memory trial for the black screen group were significantly different for males and females, the first gender difference in the study. On structural correctness males scored highest of any group, but not significantly higher than the interactive-no build males. Females scored lowest of any group but not significantly lower than the interactive-build females or the passive video females. Combining results from both genders, the black screen presentation leads to slightly but not significantly worse performance than the interactive-no build presentation. Thus far we have not found a presentation condition in which practice (actually performing the assembly) is included in instruction and performance on a later memory trial yields significantly better structural or efficiency scores than when practice is not included.

Our final manipulation to look at the effect of practice on performing a procedure from memory placed a 7-day delay between training and test for two interactive groups: one which practiced during training and one which did not. We thought that, even if practice during training did not help performance from memory when one was tested immediately after training, we might see a positive effect of practice with a delay between training and test. Once again the results showed

that we were wrong. Combining data from males and females, there were no differences in structural or efficiency performance between those who practiced during training and those who did not. (While we did not perform an independent statistical analysis with gender as a variable, it appears that building during training actually helped our (novice) female subjects, while it made no difference to our male subjects.)

This experimental work brings new questions about practice. Exactly what characterizes it, and what is its role in learning a procedure in which the motoric elements required for the task are actually known to people (everybody can join together two blocks)? At the end of this report we will discuss an experiment currently being designed in our lab which will attempt to look at these questions.

Before turning to phase 2, the lack of a gender difference on most of our assembly measures deserves comment. In some of our previous work on assembly (e.g. Baggett & Ehrenfeucht, 1988) a gender difference was our largest effect. We also have data to show that females subjectively rate themselves as novices in assembly, while males rate themselves considerably higher. A key element in making the gender difference disappear is a change in what is actually shown in the instructions (Baggett & Ehrenfeucht, in progress). Females performed as well as males when two things occurred: the video image was actually two images: one showing the (current) goal, e.g., a completed subassembly; and the second showing hands working toward the goal; and the instructions were shown in a step-by-step procedure, rather than top-down breadth first. Take away the goal, and present instructions in a non-executable order, and performance by females (but not by males) falls. When the goal is present and the order is step-by-step, we hypothesize that working memory is relieved of some of its load. We find these results intriguing but would like to see them replicated.

Phase 2. Designing and implementing a prototype "intelligent" multimedia tutoring system

Problem/goal and approach.

In the work proposed for ONR we put forth an example of a new multimedia knowledge representation to be implemented as a data structure for a tutoring system for assembly, repair, and understanding of real physical objects. The knowledge representation and the processes that work on it are an embodiment of our hypotheses about how people represent and process information. The ideas for the

knowledge representation (data structure) were an extension of our previous work in assembly; in the old work (e.g., above), the data structure consisted of nodes representing pieces of the object and links representing physical connections. The new data structure incorporated some new kinds of nodes, those indicating actions to assemble or disassemble pieces, those indicating names (for pieces, subassemblies, and actions), and abstract nodes indicating circuitry, functionality, and structure. Some of the different node types correspond to different modalities in our multimedia theoretical framework: action nodes are motoric; piece and subassembly nodes are visual, and name nodes are verbal. In addition, the new data structure incorporated two (directional) link types, one to be interpreted as subconcept, and the other as causality or expectation. (Details of the data structure are given in Baggett, Ehrenfeucht, & Hanna, 1987.)

The goals of phase 2 were to choose a reasonably complex object; to implement the data structure for the object, using videodisc; to design and implement an easily usable interface, and to test how people used the system to assemble, repair, and understand the object.

Equipment/implementation.

Before implementing the data structure for a relatively complex object, we did two implementations (verbal part only; no videodisc) for the simple flashlight given in the original ONR proposal. Mike Perry did an implementation in Lisp and John Hanna did one in C, both on a VAX 11/780. We were encouraged by the results. When the user asked a question (in a very constrained way), the graph was processed, and the "answer" to the query was presented (verbally) to the user, based on a particular graph traversal found as a result of the query. For example, when the user queried, "How do I remove the bulb?" the reply was, "Unscrew the cap. Tilt and remove the reflector from the front part. Take out the bulb." To our surprise (and amusement), when the user asked of the Lisp implementation, "How do I remove the battery from the bulb?" it replied, "Put the bulb in the reflector. Place the reflector in the top part. Screw on the cap. Unscrew the cap. Remove the batteries from the case." What it did in terms of the graph was go "up" the graph, building the whole flashlight from the bulb, and then go "down" the graph to the batteries. (We changed the graph, based on this answer, so that in a later version its response was, "It cannot be done.")

We chose a 40-piece object, a string crawler, for the complex implementation. Made from the Capsela assembly kit, it is a battery-powered object which travels forward or backward along a

string when turned on. It is shown in Figure 1 of the attached technical report. Stages in the tutor's development included:

1. Using our old techniques, we derived its "natural" conceptualization and short simple names for its parts and subassemblies. We expanded this conceptualization to one including actions (for the motoric nodes in our graph).

2. For designing linguistic access (for a subject using a keyboard), we used the naming data collected in (1) and found short unique character strings which would be used as access keys to various parts of the data structure. This technique is given in detail in Baggett, Ehrenfeucht, & Perry (1986).

3. We designed the multimedia graph to be used for the data structure. This step is analogous to the step in a production system model where the system of productions is written by a person. (The evaluation about whether the graph was correct was to be based on performance of the system when using that graph.)

4. We shot a videotape containing images of all string crawler parts and subassemblies, and of the actions of assembling and disassembling it according to the "natural" conceptualization. An image was shot for each visual node in the graph developed in (3). Each image on the videotape was to be used in many different tasks (many different graph traversals). A small number of images (less than 30 min of video) thus was meant to cover a huge amount of graph processing. The videotape was narrated using terminology derived in (1). This tape was pressed into a videodisc. A side comment is the following. An interesting problem arose in trying to shoot an image (e.g. an action) that would fit in many different contexts (graph traversals). In (linear) film, one image has only one context, so the problem of pictorial continuity is easily solved. But here one action image could be the predecessor and the successor of many different images. We fairly successfully solved the problem as follows. Each action was shot as a sequence of three images: medium shot, extreme close-up, medium shot. When a particular image was the first in a graph traversal series, the program would select medium followed by close-up. When it was in the middle, only the close-up was selected. And when at the end, the program selected the close-up followed by the medium shot.

5. The data structure was implemented in C on a VAX 11/780 by John Hanna. (Specifications were written by Rob Favero.) IBM later gave us an RT, and the implementation was moved to it. The data structure was

designed to be able to "answer" the following types of queries: (a) Show me X (for any piece or subassembly in the string crawler). (b) How do I remove/replace X? (c) Why is (or is not) something the case? (For example, Why doesn't the chain move?) (d) How does the string crawler work? The answer would consist of processing the graph to find a traversal of part of it, and then displaying on the screen images from the nodes on the traversed graph.

6. The IBM InfoWindow system which we had was an XT-PC. Rob Favero designed its connection to the IBM RT.

7. Using Composer/Conductor, Jeffery Weiss implemented on the XT a stand alone string crawler presentation. Input was via touch screen, and it was menu driven. On top of this presentation we added the "intelligent" part, with keyboard input. Thus users had two choices for input: touch a (verbal) menu label, or type some text. The latter would be analyzed by the program, and a response would be given, as explained in 5 above. The response was either a sequence of images from the videodisc, or "Will you please rephrase your query?" This second response meant that the program was unable to match the current input to any graph traversal.

<u>Experimental work and graph modifications.</u>

About 30 people (college students) tested our system, and based on their input (both computer and questionnaire) we modified the system. In particular, one thing we noticed was that our original front end which allowed people keyboard access was not very good. Based on input from the 30 participants, we tried to update and improve linguistic access. I.e., we wanted fewer "Can you rephrase that?" responses from our system, and more presentations of helpful information. One problem that stayed with us throughout the tutor's development was that people tended to avoid keyboard access when touch screen access was available. So the linguistic material from the 30 people was quite scanty and did not give us much to work with in improving the access. We will come back to this point below.

We then tested 150 people (again college students), 25 in each of six groups. The groups differed in the tasks they were asked to perform; there were two assembly tasks (one with extra distractor parts present, and one with no distractor parts) and two repair tasks (A and B), differing in difficulty. A fifth group was asked to prepare for a test on the string crawler and a sixth was asked to find bugs in the system. After completing their tasks, they were given a questionnaire which

asked them about the string crawler's functionality. A log file was automatically created as each person used the system. It indicated what key or touch area was selected, and when. As mentioned above, people were not using linguistic access very much. From 150 subjects only 481 different words (and 3642 total words) were typed, an average of only 24 per person. There were 348 questions, 229 imperatives, and 176 keywords or key phrases, an average of 5 queries per person. People were not very inventive or varied in their typing. Further, they tended to type what they SAW in the menu labels much more frequently than what they HEARD in the narration. So (after moving to Michigan) we tested two new groups (25 college students per group) who were allowed no linguistic access but touch screen only. One group had the structured part of the tutor, with no "intelligent" part. The other was given free unorganized browsing, with no structure. This last group could "jump" from one part of the videodisc to another, by touching the word "jump," and then specifying an integer to indicate how many "events" ahead (see below) they wished to jump. Both of the new groups did repair task A.

Several types of data analysis were performed on the data from the eight (six old and two new) groups. The first question we asked was, how similar are the behaviors of people in the different groups? In particular, did people in different conditions spend similar amounts of time viewing the same parts of the videodisc? There were 196 "events" in the presentation (an event was basically one or more pieces of videodisc). The log file told us how long each person spent in each event. We assigned to each person a 196-element vector, each element indicating how long the person spent in that event. We determined the distance between any two people in a group (using the L^2-norm), and the distance between any two groups (which we defined as the average distance between any two people in the two groups). For each group, we calculated its closest neighboring group (using the average distance). We did a cluster analysis on these data and found only one main cluster, containing the six touch screen plus linguistic access groups. The two new groups, who used only the touch screen, were outliers, even though they did a repair task, identical to the task performed by one of the other six groups. This result indicates that behavior on our system depends more on the *environment* one is in than on the *task* one is doing, at least in terms of amount of time spent in various events.

The next question was, how varied is behavior within a group? From the above calculations we knew the average distance of each group member from every other member of his or her group. We drew a diameter of one standard deviation around each group (about 2/3 of members' behaviors fall within that diameter). Thus the diameter gave

us an idea of how dispersed the behavior in each group was. We found these diameters to be huge, in comparison to the distances between groups. All groups overlapped substantially in their behaviors. We interpreted this to mean that individuals were extremely varied in their behaviors, even when they were working on the same task. Each person seemed to explore a particular part of the tutor, and the part explored was fairly unique to the individual. The large variety of behaviors within a group we found quite surprising, since the tasks were the same. We do not attribute the different behaviors to individual differences. Rather, we think their behaviours are analogous to exploring different parts of a map: people's behavior is creating a map (where the map is the computer environment), and then finding a solution corresponding to a specific task based on the map.

To determine which mode of input, touch screen or keyboard, users in the six groups given the two modes preferred, we determined for each log file entry whether it came from keyboard or touch screen, and we summed up times for the two modes. We learned that in all six of the groups in which keyboard was available, subjects spent approximately 75% of their time using touch screen. And more than 10% of the subjects never used the keyboard once. Subjects explained on post-questionnaires that they much preferred touching to typing. Comments were, "The touch screen choices tell me what information is available," "I didn't know what to type," "I don't have to think when I touch," "Touching is easier than typing," etc.

The success rate for assembling and repairing the string crawler was close to 100% in all groups, and 7 of the 8 groups spent about the same time working on their various tasks (between 33 and 39 min). The group given unorganized access spent significantly more time, i.e., 51 min. Percentage correct on the string crawler test of understanding was uniform and not very high (less than 50%) in all groups. There was basically a ceiling effect on the assembly and repair tasks, and not much conceptual understanding (how and why something works). In hindsight we should have selected a more complex object on which to base the tutor, and we should have presented more conceptual and perhaps less procedural information.

Positive and Negative Aspects of the Tutor, and the Future of this Approach.

One positive aspect to the implemented data structure was its compactness: A fairly small data structure covered a large amount of processing. But the data structure was not modular, and a problem arose

when it was modified. (Modification was done in order to accommodate additional processing.) Modification created unpredictable side effects that influenced other processes that were previously constructed and that were not "protected" from such side effects. For example, adding an extra feature so that the system could correctly answer the question "how?" changed how the system answered the question "what?" in quite an unpredictable way. So this created a problem with the expandability of the system.

Also, independent of the fact that the linguistic front end was not done as correctly as it should have been, we had made an a priori assumption that subjects would use far more access from the keyboard than they actually did. A clear finding was that subjects avoided using the keyboard when they had other (touch screen) access. Thus, as mentioned above, the textual material provided by subjects, and which we used to design access, was small and irregular. Our linguistic front end was reacting to text material, and it could not handle very many queries.

Is there any future to this type of data structure? To review, if we set up process one, for example, to answer the question why, this corresponds to some traversal of the graph. Process two gets another traversal that heavily uses the same nodes as process one. So many processes can be accommodated on the same graph. But now suppose a third process is added, and it requires extra links and perhaps extra nodes. The unexpected effect was that process one or two would find a new link (path) and use it. There were two effects to this:
(a) Repetitions could be created. That is, loops could be created in the process: some material could be processed over and over again. This occurred because the expansion added extra links and nodes.
(b) Wrong answers could be created. Not finding an answer corresponds on our system to finding a dead end. Suppose process one when first implemented would occasionally (correctly) respond, "I don't know." Afterwards, new nodes or links might be added, so that process one now finds new routes and gives spurious answers.

Could (a) and (b) be avoided? The answer is yes, and relatively easily. But redoing the graph would require reprogramming the whole data structure. Performance obtained on the basis of users' selection of visual material was already creating a ceiling effect (almost everyone could perform his or her task perfectly), so changing the data structure under these conditions would not effect a measurable difference. For the size of the problem which we undertook, we have a satisfactory solution, without an "intelligent" data structure. Namely, we have one very

specially prepared videodisc that covers a large number of tasks. How it was prepared is very important. A presentation using touch screen only, with no data structure processing, yields as good performance as we could get. This brings us to one general observation: The performance of an elaborate system depends on the amount of information users provide. With both touch screen and keyboard access, users do not provide much information from the keyboard.

Phase 3. Graphics-based procedural instructions

Problem/goal and approach.

In phase two we had learned that human performance and understanding after studying well-designed and well-organized instructions with simplified input was as good as that from so-called "intelligent" instructions. In phase three, carried out at the University of Michigan, we investigated the role of organization and access in well-designed graphics (rather than videodisc) instructions. Upon my move to the School of Education at the University of Michigan in September 1987, the Office of Naval Research very generously allowed the purchase of a large amount of equipment, which was unavailable at the School, and much needed. Included were two MacIntosh II workstations, with very large external hard discs and many pieces of software. As described below, this was the equipment used for phase three.

In earlier work we had learned that a good (i.e., "typical") organization in passive (videotape) instruction leads to better performance than a "minority" conceptualization (Baggett & Ehrenfeucht, 1988). The question we asked in this study was, how important is a good organization when the instructions are *interactive* rather than passive? Suppose we shuffle up the underlying organization (i.e., the sequence that one gets when one selects forward arrows), but make sure that a user can get from one piece of information to another in a short number of moves (choices). Will the user then have more difficulty (or less success) than if the presentation's underlying structure is well organized?

At the end of this report can be found a technical report describing the study. Only a very brief summary is given here.

Implementation.

The object was the string crawler used in phase 2. We had derived

its "typical" tree structure (division into subassemblies) in phase 2, and a graphics frame (with animation) for each leaf and node in the tree (34 in all) was prepared, using the Course of Action authoring language for the Macintosh II. We selected three organizations (sequences) of the frames. The first ordering was such that,when one viewed it from first to last (clicking on forward arrows using a mouse), one would observe a correctly- (and typically-) built string crawler. The second ordering gave a randomly shuffled sequence when viewed from first to last. And the third grouped together frames that had parts of the string crawler in common, even though the sequencing was otherwise not meaningful (see the discussion of visual cohesion in the technical report).

In addition to access via forward arrows, one could select one or more objects in a frame (indicated by stars), and one would go to the next frame which contained that object. We termed this access "hypergraphics," rather than hypertext.

Experimental work.

Ninety-six subjects were tested, 16 males and 16 females in each of three groups, each group given different instructions. Each person's task was to repair the string crawler,which was identically broken for all groups. The basic questions were: (1) How does access (use of forward and backward arrows versus use of stars) depend on the underlying sequence? (2) How does underlying sequence influence performance? We thought that access choice would vary as a function of underlying sequence: people given random orders would select more stars, while people given the typical order would select more forward/backward arrows. We also thought meaningful sequences would lead to better performance than random sequences.

Results/Discussion.

The surprising finding was that there are no differences among the groups in either use of access or performance on the repair task. We offer a post hoc explanation: the instructions were interactive, and therefore users held no expectations about organization. What was important was short access (i.e., a small number of choices gets the user from where he or she is to anywhere he or she wants to go). We were able to calculate the shortest average distance (number of choices) from frame i to frame j for each of the presentations. We found it to be 5.6 (typical sequence); 2.8 (random sequence); and 3.35 (sequence grouped by visual cohesion). Our observation is that perhaps deep hierarchical menus are not the best way to design access. Perhaps all that is needed

is short access.

Final Comments on the Project.

The work done on this project covered several areas. In the first phase, we rather accidentally began looking at the role of practice in procedural instruction, as the result that practice does not always help and sometimes hurts refused to go away. The research has led us to begin to examine more closely the phenomenon of practice. In my lab at Michigan we are almost ready to begin testing subjects to examine one issue involving practice. We hypothesize that when one practices, the concepts that one is forming become somewhat "frozen" and less modifiable than when one does not practice. The question we are looking at is, is a motoric component (actual actions in the real world) necessary to get this "freezing"? We consider the question to be fundamental, and it is a key question in our evolving theoretical framework of learning and memory. In a nutshell, we are looking at learning as having two components, understanding and skill aquisition (coming through practice). As mentioned above, we consider understanding (analogous to forming an algorithm) to be a cognitive process, and skill acquisition (analogous to executing an algorithm) to be a non-cognitive process. We are currently investigating this distinction for *mathematics education*.

In phase two we learned that developing a so-called intelligent multimedia tutoring system is indeed difficult. As discussed above, there were problems (although not necessarily insurmountable) with the data structure and its processing, and with linguistic access. In addition, the well organized non-intelligent part of our tutor led to performance that was as good as that obtained when the intelligent part was added. This may have been because the object (string crawler) was not complex enough, or because of the linguistic access and processing problems. But it also could indicate that well organized information is sufficient for (adult) humans, and that a so-called intelligent part is not necessary. After coming to Ann Arbor, I did not have the necessary computer science connections to continue in any large fashion the videodisc tutor's development (although we were able to get it up and running, to develop one new videodisc implementation, and to test 50 students using it). Thus I consider that the question of whether "intelligence" is necessary in procedural instruction is still open.

Phase three was our first experiment using graphics and animation (rather than videodisc) on the Macintosh II. Its questions were not very theoretical, but were definitely practical. And its main result, that

organization doesn't matter for the interactive instructions we developed, was surprising and deserves further investigation. A comment is also in order regarding comparing videodisc versus graphics instruction, which we can of course do only to a very limited extent here. Looking at the post-questionnaire data from the graphics experiment we learned that people were confused by the two-dimensional drawings of the three-dimensional string crawler parts, and that sometimes they could not discern their orientation, or what was behind what. (We note that the graphics were done by a professional graphics artist; examples can be seen at the end of the attached technical report.) These confusions did not occur with video images. There was a particular *graphic* in both video and graphic presentations which was a schematic diagram showing the string crawler's wiring. People in all groups who found this frame spent a lot of time viewing it. This brings up the question of how to design graphics to get across different kinds of information, for both building concepts and executing procedures.

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Palmiter, S., Elkerton, J., & Baggett, P. Animated demonstrations versus written instructions for learning procedural tasks: A preliminary investigation. International Journal of Man-Machine Studies, in press. (A longer version is: Palmiter, S., Elkerton, J., & Baggett, P. Animated demonstrations versus written instructions for learning procedural tasks. (Tech. Rep. C4E-ONR-2). Ann Arbor, MI: University of Michigan, Center for Ergonomics, 1989.)

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Figure Caption

Figure 1. Design of interactive instructions for the lift in phase 1. Arrows indicate options available to the user via touches to labels on the touch screen. Touching "next" took user to next unit. "Short replay" replayed unit just viewed. "Long replay" replayed previous two units. "Extra-long replay" replayed entire subassembly. And "Replay whole presentation" replayed from the beginning.

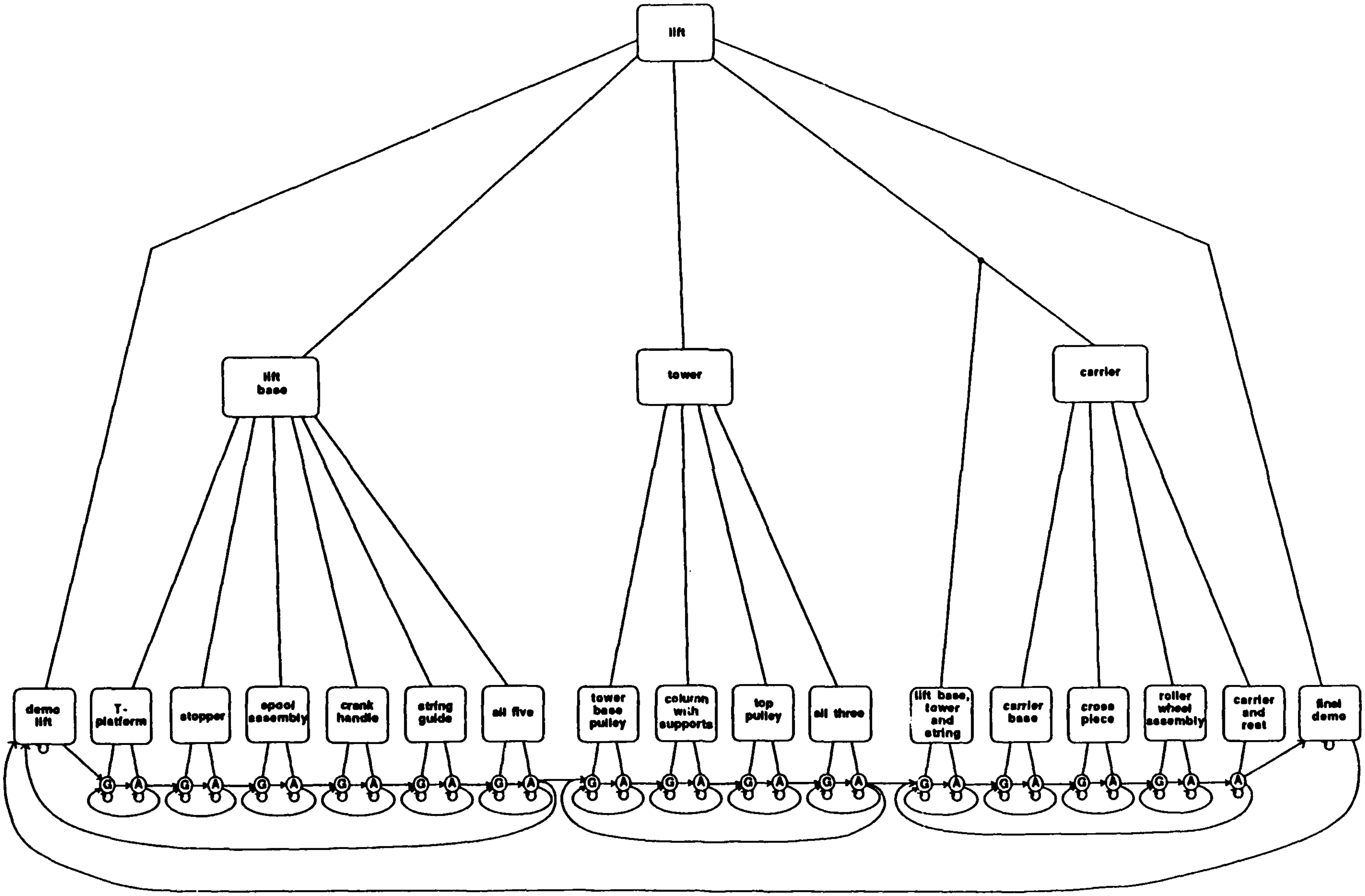
lift
lift base
tower
carrier
demo lift
T-platform
stopper
spool assembly
crank handle
string guide
all five
tower base pulley
column with supports
top pulley
all three
lift base, tower and string
carrier base
cross piece
roller wheel assembly
carrier and rest
final demo
G
A

Figure 1

Sequencing and Access in Interactive Graphics-based Procedural Instructions

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Abstract

When procedural instructions are presented noninteractively and are structured well (i.e., in a "typical" way), people can perform the procedure better later from memory than when the instructions are presented atypically. The question in this study was, what is the role of organization (sequencing) when the instructions are presented **interactively**, so that people can choose their own paths through the material? Using computer graphics and animation, we designed three sets of instructions showing the assembly of a 40-piece object made from an assembly kit. For the first instruction set, access by forward arrows gave the "typical" sequence. For the second, access by forward arrows gave a random sequence; and for the third, such access put together information that was similar in terms of visual elements in common ("visual cohesion"), but not in terms of meaningful organized sequencing. Another kind of access was also available: one could click on an object and would go to the next "frame" which contained that object. We expected that people in the three groups, given a repair task, would differ in their performance on the task and in their use of access. Surprisingly, we found no differences. We offer a post hoc explanation: when instructions are interactive, organization does not matter, but access does. As long as one provides, as we did, a short path between any two nodes (in our case, "frames,") the rest is not so important. This could mean that elaborate hierarchical menus are not the best way to design access.

Introduction.

A recurring theme in some of our earlier work is the strong role of organization in procedural instructions (Baggett & Ehrenfeucht, 1988). When instructions are presented noninteractively via videotape and are structured well (i.e., in a typical or natural way), individuals can perform the procedure better later from memory than when instructions are structured in a less typical way. Thus an old finding is that if the order of learning is strictly enforced by a presentation, then sequencing plays an essential role. In the 1988 study, the procedure was to build an 80-piece object, a lift, made from pieces in the Fischer-Technik assembly kit.

The question in this study is whether sequencing is important when subjects are provided with well designed free access to the information, i.e., when they can pretty much do what they want, viewing the information in many different orders. The object used, a string crawler made from 40 pieces in the Capsela assembly kit, is shown in Figure 1. Figure 2 shows a possible tree structure for the string crawler. This structure has been determined to be the "typical" one, using techniques from Baggett & Ehrenfeucht, 1988. Following along the leaves of the tree from left to right, taking the named parts and assembling them, one gets a correctly built string crawler. This sequence, if enforced in a noninteractive presentation, should lead to better performance from memory than some other atypical sequence.

We first explain the notion of visual cohesion and the design of the presentations and their implementation, followed by the experimental procedure. We then present the rather surprising conclusions and a hypothetical explanation which, if correct, can have useful practical consequences.

Visual Cohesion.

Besides the typical sequence, we chose four other sequences to test as well, based originally on notions of text coherence (Kintsch &Vipond, 1977; Kintsch & vanDijk, 1978) and text cohesion (Halliday & Hasan, 1976). Briefly, a text base in Kintsch's sense is coherent if it is connected by argument repetition. For Halliday et al., cohesion occurs through word repetition, a noun and its pronoun referent, use of synonyms, etc. We (Baggett & Ehrenfeucht, 1982) extended these notions to visual cohesion and quantified the visual cohesion in a pictorial sequence taken from a movie. In this study we use the same techniques. We prepared 41 frames, to correspond with the leaves and higher nodes of the tree in Figure 2. A cohesion graph of these 41 frames, in their typical order, is shown in Figure 3. The cohesion graph is formed as follows. The frames contain computer graphics of string crawler parts. We selected 21 elements (parts of the string crawler) occurring in the frames to include in the cohesion analysis. For each element, we counted the number of times it occurred in adjacent frames. For example, element 1 (a motor) occurred in frames 1, 2, 3, 5, 7, 30-34, 37, 38, and 40. Its number of adjacencies was thus 7 (for occurring in adjacent photos 1-2, 2-3, 30-31, 31-32, 32-33, 33-34, and 37-38). We summed the number of adjacencies over all elements to determine a cohesion value for the sequence. The frames in their typical order have a cohesion value of 96.

We chose the four other sequences as follows. First, the frames were randomly ordered 1000 times, and the mean cohesion value was found to be 45. So we selected two orders with value 45. Then, using "hill-climbing" techniques, again 1000 times, we constructed random sequences with high cohesion. They had a mean cohesion value of 131. (We selected two orders, rather than one, to decrease any idiosyncratic effects accidentally arising from one sequence.) Randomization of the orders was

meant to destroy any meaningful sequencing. Because we found no differences for groups receiving the two random sequences, and also none for groups receiving the two hill-climbing sequences, the data in each case are combined. Thus there are 3 groups reported: 1 (typical), 2 (random), and 3 (hill-climbing). Each adjacent pair in group 1 has, on the average, 96/40 = 2.4 elements in common. The numbers are 45/40 = 1.13 for group 2, and 131/40 = 3.28 for group 3.

Design of Materials.

The presentation was implemented on a MacIntosh II using the Course of Action authoring language. Access was via mouse clicks. Options available in each frame were as follows:

1. Forward arrow. Goes to "next" frame around a "clock face."
2. Backward arrow. Goes back one frame around the clock face.
3. A star by an object. Goes to next frame around clock face that contains the object. (This is access by visual cohesion.)
4. Previous button. A stack is kept, and "previous" goes in order to elements on the stack, allowing the user to retrace steps.
5. Exit button. Asks, "Do you really want to exit?"; exits if user clicks yes, and takes user back if user clicks no.
6. Activity buttons. Cause animation such as assembly of parts shown.

It is important to remember that the only item varied in the five presentations was the **sequencing**, i.e., what happens when the user selects the forward and backward arrows. Access via stars gave the same results in all groups.

Basic questions.

In the experiment, subjects were given a broken string crawler, told that it doesn't work, and asked to fix it. They were also told that the presentation contained information that would allow them to fix it. The basic questions were:

• How does access (use of forward and backward arrow versus use of stars) depend on order?

• How does order influence performance?

Our original hypotheses were:

1. Meaningful sequences will lead to better performance than random ones. (Group 1, given the typical sequence, should outperform group 2, given the random sequences.)

2. People given not meaningful, but cohesive, sequences (group 3, given sequences determined by hillclimbing) will follow the forward and backward arrows for access, while people given random sequences (group 2) will follow stars.

Thus we predicted that access choices would vary as a function of sequence.

Implementation.

The drawings are two-diminsional, black-and-white, with no hands. Names of parts and subassemblies, derived using techniques in Baggett, Ehrenfeucht, and Perry (1986), are printed on the frames. The interface is meant to be obvious or invisible, i.e., no training is required in order to use it. The authoring language used, Course of Action, is similar to HyperCard. Logfiles were kept of each user action, for later data analysis.

Frames 0 and 1 are the same for all groups. Frames 0, 1, 2, 3, and 4 for group 1 are shown in Figure 4.1. Frames 2 through 4 for one of the random groups are shown in Figure 4.2. And frames 2 through 4 for one of the hill-climbing groups are in Figure 4.3.

Dependent Measures.

There were three kinds of dependent measures:

1. Using the system. Proportion of forward, backward, previous, and click-on-star choices; total time on system; mean time in frame; average number of frame visits; average length of a string of "previous" choices;

average number of activity buttons selected.

2. Performing the task. Does the string crawler function? Did the user fix what was wrong with it?

3. User satisfaction (post questionnaire). Questions on screen design and options, getting lost, and subjective satisfaction.

Subjects. Ninety-six college students served as subjects, 16 males and 16 females in each of three groups. They were paid $5.00 per hour for participating.

Results and Discussion.

Results on use of the system are given in Table 1. Figure 5 shows the percentage of forward, backward, previous, and click on stars choices by group. The surprising thing to notice from both Table 1 and Figure 5 is that there are no differences among the groups. Figure 6 shows the time spent in a frame, by group and by frame, with the order of time in frame decreasing. It shows that there are a few frames which people spend lots of time visiting (and that these are the same for all groups). The rest of the frames are visited only briefly. The three most frequently visited frames are the first one (the whole string crawler shown in Figure 5.1), frame 38 (frame 3 in the hill-climbing sequence of Figure 5.3), and frame 30 (frame 2 in the hill-climbing sequence of Figure 5.3).

Table 2 gives the scores on performance (whether the string crawler works, and whether all the repairs were made correctly) by group. Again, the three groups perform essentially identically, and almost perfectly. There were no gender differences in performance.

Table 3 gives the ratings on the postquestionnaire, with 0 being worst and 10 being best. Again, there were no group differences. The sequencing was not particularly clear for any group, but getting back was easy. Overall, the screen design was judged fairly good, but all groups wanted more stars to click on. And overall the task was fun and

satisfying.

Interpretation.

We expected that the underlying organization in interactive instructions would make a difference in use of different kinds of access and in performance of the task. Namely, we expected that people with randomized orders would not use forward and backward arrows very much, because of the lack of logical connections between consecutive frames. Or, if they did, we thought it would significantly decrease the quality of their performance. But it did neither. Why? We offer the following post hoc interpretation. The instructions were **interactive**, and therefore subjects had no expectations about organization. In interactive instructions, organization does not matter, but access does. Our current hypothesis is that, as long as one provides a short path between any two nodes (in this case, frames), the rest is not so important. A theorem by Bollobas (1985, p. 241) says that for most graphs of n nodes, in which from each node one can go to k others, the shortest average distance is approximately $\log_{k-1} n$. Here, n=41. We calculated the shortest average distance from frame i to frame j for the presentations for groups 1, 2 (a and b), and 3 (a and b). They were: group 1, 5.6; groups 2 (a and b), 2.8; and groups 3 (a and b), 3.35. In actuality, group 1, with the typical organization, actually had the longest average path length of all of the groups, and groups 2 (randomly sequenced) had the shortest!

We note that the Bollobas theorem says that if there are 11 links from each node, and 1,000,000 nodes, the shortest average distance is approximately $\log_{10} 1{,}000{,}000 = 6$. Thus path lengths grow very slowly compared to number of nodes.

Conclusions.

We started this paper by noting that organization is important when the order of learning is strictly enforced by a presentation. But the

results of this study indicate that organization does not seem to be important when well designed free access to the information is provided, i.e., (hypothesis) as long as there is a short path between any two nodes. This could mean that elaborate, deep hierarchical menus are not the best way to design access.

Acknowledgments

We thank Brian Murphy for implementing the random and hill-climbing cohesion programs. We also thank the Office of Naval Research for their support of this work under contract N00014-85-K-0060, Cognitive Sciences Division, Susan Chipman, Director.

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Table 1
Use of System
(There were 16 males and 16 females in each group.)

	Group 1 (typical)	Group 2 (random)	Group 3 (hill-climbing)
mean time on system (minutes)	30.8	32.7	36.6
mean time in frame (seconds)	19.1	20.4	19.3
mean number of frame visits	95.7	97.4	113.3
average length of "previous" string	2.4	2.3	2.2
average number of times activity buttons selected	19.0	19.7	29.1

Table 2
Performance Scores by Group

	1 (typical)	2 (random)	3 (hillclimbing)
functionality of string crawler (20 points possible)	17.0	16.9	16.0
corrections made (35 points possible)	32.0	32.6	32.2

Table 3
Postquestionnaire Measures
(0=worst; 10=best)

	(typical)	(random)	(hillclimbing)
sequence confusing/clear	4.9	3.6	4.4
next screen predictable/unpredictable	4.6	3.8	4.4
maintain a sense of where you are	4.8	4.9	5.3
getting lost (10=didn't get lost)	5.7	6.0	6.1
getting back	8.4	8.4	9.0
clickable stars hard/easy to find	8.3	8.0	7.9
discern orientation of parts	6.2	5.7	5.6
layouts cluttered/orderly	7.6	6.9	6.9
number of click options 0=too few; 10=too many	2.3	3.0	3.9
hard work/fun	7.9	8.0	7.3

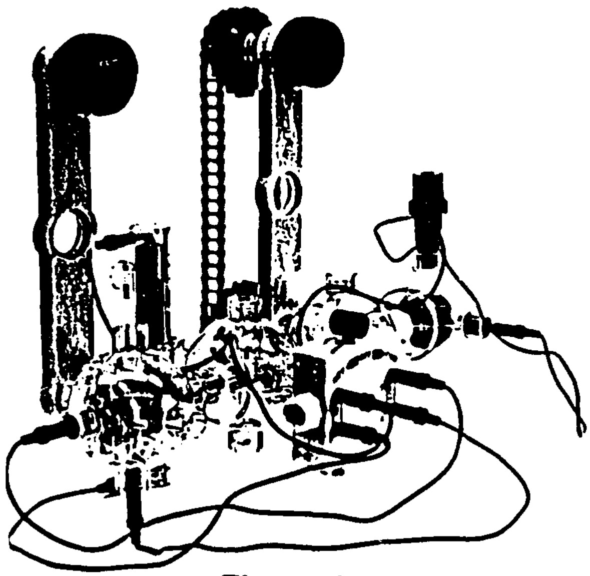

Figure 1

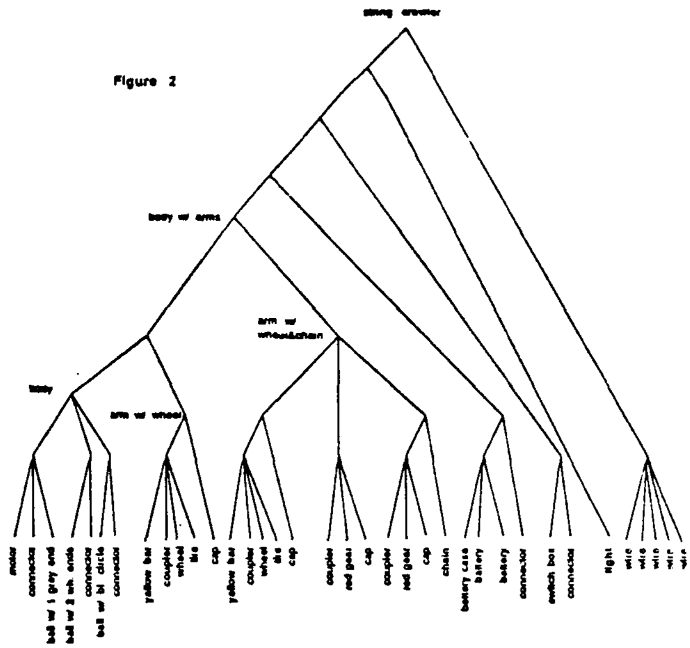

Figure 2

```
                          FRAME NUMBER

        12345678911111111112222222222333333333344
                 01234567890123456789012345678901
ELEMENT                                            NUMBER OF ADJACENCIES
       1[111 1 1                      11111  11 1 ]7
       2[                                         ]0
       3[ 11 1 1                       1111       ]4
       4[                                         ]0
       5[11 11 1                      11111  1    ]6
       6[                                         ]0
       7[11   11                      11111  111  ]8
       8[1      11 1                  11111  1    ]5
       9[1      11                    11111  1    ]5
      10[1      1 11                  11111  1    ]5
      11[                                         ]0
      12[                                         ]0
      13[1          11 11 11 1 1      1 111  1    ]5
      14[                                         ]0
      15[1          1 11111111 1      1 111  1    ]9
      16[             111                         ]2
      17[                                         ]0
      18[               1111 1 1                  ]3
      19[1          1    11111 1      1 111  1    ]6
      20[                                         ]0
      21[           1      111 1        1         ]2
      22[           1       11 1        1         ]1
      23[                                         ]0
      24[1          1         11      1 111  1    ]3
      25[                                         ]0
      26[1                      1111  1  111 11  1]6
      27[1                      1111  1  111 11  1]6
      28[                                         ]0
      29[                                         ]0
      30[1                          111   1  11111]6
      31[                                         ]0
      32[1                            1     1111  ]3
      33[                                  11     ]1
      34[                                         ]0
      35[                                         ]0
      36[                                         ]0
      37[                                         ]0
      38[                                         ]0
      39[                                         ]0
      40[1                            1    1  1111]3

                                                   96 -- TOTAL
```

Figure 3

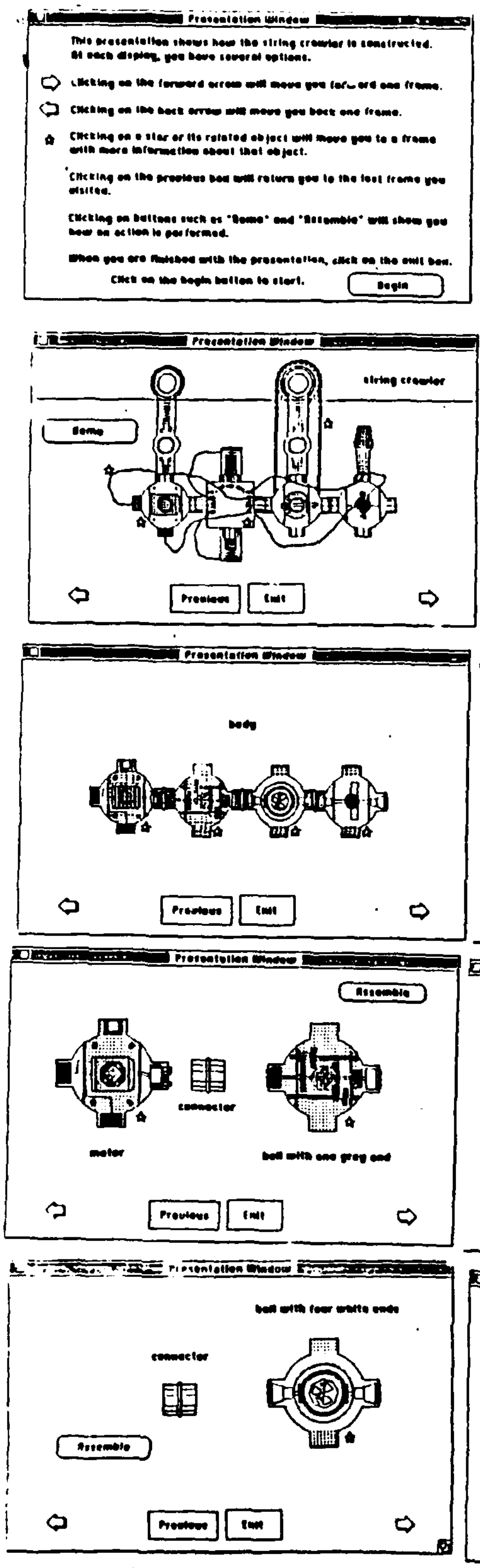

Figure 4.1

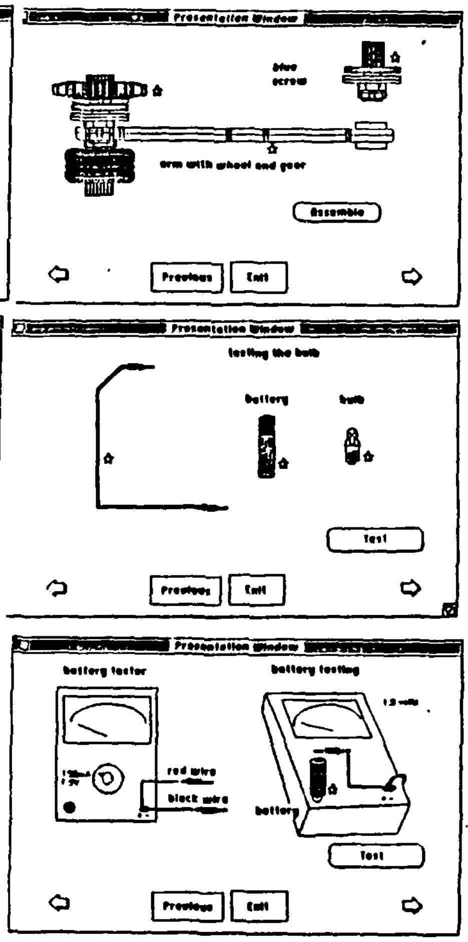

Figure 4.2

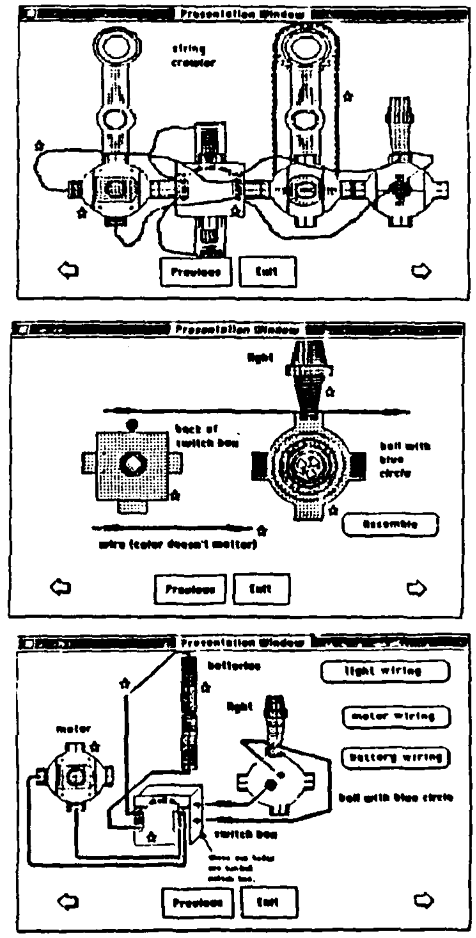

Figure 4.3

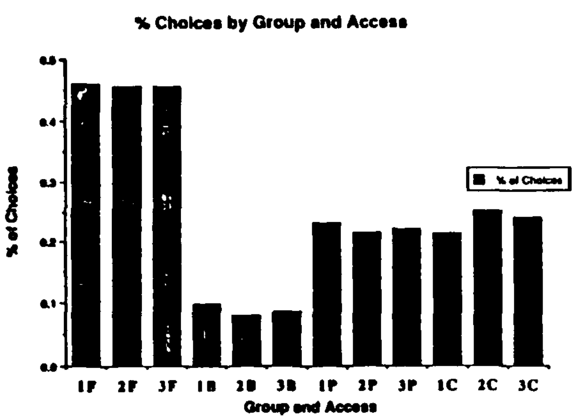

Figure 5

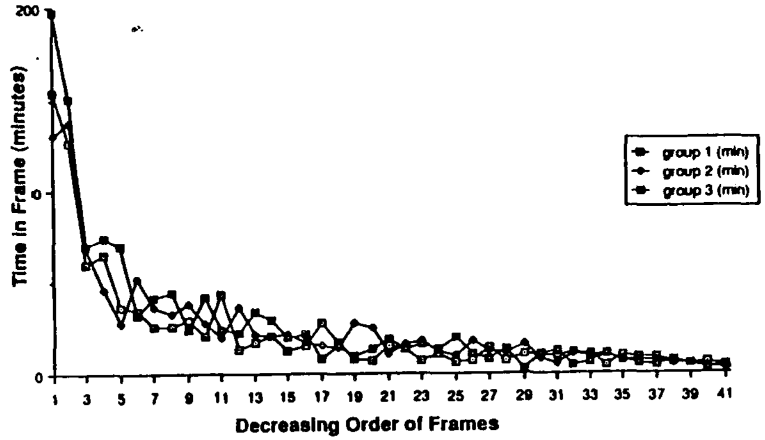

Figure 6

Figure Captions

1. A 40-piece object, a string crawler, made from the Capsela assembly kit.

2. The typical tree structure of the string crawler.

3. Cohesion graph of the typical sequence.

4.1 Frames 0, 1, 2, 3, and 4 from the typical presentation.
4.2 Frames 2, 3, and 4 from one of the random presentations.
4.3 Frames 2, 3, and 4 from one of the "hill climbing" presentations.

5. Percentage of access choices by group. F = forward; B = backward; P = previous; C = click on star.

6. Time in frame as a function of group (32 subjects/group).

Appendix

This appendix contains papers, talks, and technical reports on the Office of Naval Research Contract, Designing and Implementing an Intelligent Multimedia Tutoring System for Repair Tasks (N00014-85-K-0060).

Papers.

Baggett, P. Mixing verbal, visual, and motoric elements in instruction: What's good and what's not? Proceedings, International Visual Literacy Association, Twentieth Annual Conference, in press.

Baggett, P. & Ehrenfeucht, A. Textual and visual access to a computer system by people who know nothing about it. Proceedings, Sixth International Conference on Systems Documentation, Association of Computing Machinery, in press.

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Talks.

Baggett, P. & Guzdial, M. Organization and access in graphics-based procedural instructions. Michigan Association for Computer Users in Learning, Detroit, April 1989.

Baggett, P. & Ehrenfeucht, A. The role of calculators and computers in mathematics education. American Educational Research Association Annual Meeting, San Francisco, March 1989.

Baggett, P. Learning and practicing procedures. Office of Naval Research Contractors' Meeting on Intelligent computer aided instruction, Orlando, March 1989.

Baggett, P. & Ehrenfeucht, A. What is the role of practice in cognition? Twenty-ninth annual meeting, Psychonomic Society, Chicago, November 1988.

Baggett, P. & Ehrenfeucht, A. Textual and visual access to a computer system by people who know nothing about it. Sixth International Conference on Systems Documentation, ACM, Ann Arbor, MI, October 1988 (invited).

Baggett, P. Mixing verbal, visual, and motoric elements in instruction: What's good and what's not? Twentieth Annual Conference, International Visual Literacy Association, Blacksburg, VA, October 1988 (invited).

Baggett, P. Using computers intelligently in education, and Using interactive videodisc: A surprising finding. Virginia Association of College Teachers of Education annual fall retreat, Richmond, VA, Sept. 1988 (invited).

Baggett, P. Promises and problems of computers in education. Florida Model Schools Consortium, Living Seas, EPCOT, Orlando, September 1988 (invited).

Baggett, P. The role of practice in videodisc-based procedural instructions, and Learning in multimedia instructional environments.

Seminar for Deans of Schools of Education, Ann Arbor, June 1988 (invited).

Baggett, P. Designing, implementing, and using a multimedia tutoring system for procedures. American Educational Research Association annual meeting, New Orleans, April 1988.

Baggett, P. How people maneuver in multimedia instructional environments. Michigan Association for Computer Users in Learning, Grand Rapids, March 1988.

Baggett, P. Multimedia instructional environments. Office of Naval Research Contractors' Meeting on Advanced Educational Systems, Pittsburg, March 1988.

Baggett, P. How people use a multimedia computer system for interactive procedural instructions, Psychonomic Society, Twenty-eighth annual meeting, Seattle, November 1987.

Baggett, P., Ehrenfeucht, A., & Hanna, J. Implementing a multimedia knowledge representation for interactive procedural instructions, Second Annual Rocky Mountain Conference on Artificial Intelligence, June 1987.

Baggett, P. Mixing practice with interactive procedural instructions does more harm than good. Cognitive Research Group, Princeton University (invited), March 1987.

Baggett, P. Putting visual material into a database for a so-called intelligent tutor: problems and solutions. Office of Naval Research Contractors' Meeting, Yale University, March 1987.

Baggett, P. Learning procedures from interactive videodisc vs. passive video. Psychonomic Society Twenty-seventh Annual Meeting, New Orleans, November 1986.

Baggett, P. Interactive vs. passive multimedia instructions. Symposium on Human-Computer Interaction and Cognitive Engineering. 1986 IEEE Conference on Systems, Man, & Cybernetics, Atlanta, October 1986. (invited)

Baggett, P. & Ehrenfeucht, A. Developing a so-called intelligent tutor using videodisc. Advanced Educational Systems Group, IBM-Atlanta, October 1986 (invited).

Baggett, P. Motoric, visual, and linguistic concepts: their formation and integration in memory. Symposium on Acquiring Knowledge from Text-Picture Interactions. Tubingen, West Germany, July 1986 (invited).

Baggett, P, Ehrenfeucht, A., & Perry, R. A technique for designing computer access and selecting good terminology. First Annual Rocky Mountain Conference on Artificial Intelligence. Boulder, CO. June 1986.

Baggett, P. An interactive multimedia tutor for procedural tasks. American Association for the Advancement of Science - Southwestern and Rocky Mountain Division. Symposium on Cognitive Science: Theory, Methodology, and Application to Human-Computer Interaction. Boulder, Co. April 1986 (invited).

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